Lasers in Surgery and Medicine 21:198–202 (1997)

Intrarenal Use of the Holmium Laser

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Background and Objective: **We investigated the safety, effectiveness, and techniques of the holmium (Ho:YAG) laser intrarenally. Data are presented on 52 patients who were treated with the Ho:YAG laser intrarenally for urinary calculi or neoplasms.**
Study Design/Materials and Methods: **The Ho:YAG laser has a wavelength of 2,100 nm, which is delivered in pulsed fashion via a small flexible quartz fiber (365 μm), which is placed through a working channel (>2.2 Fr) of a small diameter endoscope.**
Results: **Sixty-three intrarenal procedures were performed with the Ho:YAG laser for calculi and neoplasms. Twenty-four procedures were performed for intrarenal neoplasms. Average total energy used in these patients was 2.61 kilojoules (kJ) with a maximum of 15.28 kJ. Thirty-nine procedures were performed for intrarenal calculi; 7/39 procedures were approached percutaneously. Average total energy in stone patients was 5.41 kJ with a maximum of 37.77 kJ.**
Conclusion: **The Ho:YAG laser can be used safely and effectively to treat intrarenal calculi or neoplasms. All types of calculi were fragmented and all patients with intrarenal tumor were treated successfully. There were no vascular or renal injuries and there was no evidence of renal loss. No intrarenal strictures were seen on follow-up. The Ho:YAG laser energy can be delivered through a small flexible quartz fiber passed through a small diameter endoscope. The techniques and applications of the Ho:YAG laser make it well suited for urologic application. Lasers Surg. Med. 21:198–202, 1997.**

Key words: calculi; endoscopy; holmium; intrarenal; laser; tumor

INTRODUCTION

Applications for endoscopy of the upper urinary tract continue to evolve. Ureteroscopy, initially restricted in its use to the distal ureter, is currently being used for inspection and treatment in more proximal portions of the upper urinary tract [1,2,9]. Access to the intrarenal collecting system, both retrograde and antegrade, allows the urologist to treat intrarenal lesions endoscopically. For successful treatment, it is essential to have smaller and effective devices for stone fragmentation and tissue ablation.

Lasers play a critical role in the therapeutic applications of endoscopy. The pulsed dye laser, the first laser accepted for stone fragmentation, allowed small endoscopes to be used in a therapeutic role [3–5]. The neodymium-YAG (Nd-YAG) laser is another device that can deliver light via a small fiber. This fiber can be passed through the working channel of a small diameter endoscope to treat ureteral and intrarenal lesions. The relative ineffectiveness of the pulsed dye laser for cystine and calcium monohydrate calculi and the thermal damage by Nd:YAG laser limit their use [6,7].

The newest laser available for urologic use is the holmium-YAG (Ho:YAG) laser. It can fragment all types of calculi and can also ablate tissue by delivering energy through small quartz fibers that can be placed through the working channel of a small diameter endoscope [7,8,11,13]. The Ho:YAG laser has been described for treating both proximal and distal ureteral pathology [8,11,12].

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Accepted 29 August 1996.

We explore the effectiveness and safety of the Ho:YAG in the intrarenal collecting system.

MATERIALS AND METHODS

From 5/94 to 1/96, the Ho:YAG laser was used intrarenally in 63 procedures on 52 patients (ages 27–88). Intrarenal treatment was performed either by retrograde flexible ureteroscopy or percutaneous nephroscopy. Patients were treated for intrarenal tumor or urinary calculi.

Thirteen patients (8 males, 5 females) underwent a total of 24 procedures for intrarenal neoplasms. Twelve patients had biopsy proven low grade (grade I-II) intrarenal transitional cell carcinoma (TCCa). Nephroureterectomy is the standard therapy for patients with upper tract TCCa. Solitary kidney, renal insufficiency, bilateral disease, or severe medical problems prevented these patients from undergoing nephroureterectomy. One patient had high grade intrarenal TCCa in a solitary kidney and was treated for gross hematuria. All patients in this group were treated via retrograde flexible ureteroscopy. Follow-up consisted of retrograde pyelogram with surveillance ureteroscopy at 3–6-month intervals.

Thirty-nine patients (21 males, 18 females) underwent a total of 39 procedures for intrarenal calculi. Five patients had calculi consisting of cystine, 15 had calcium oxalate monohydrate; the other 19 had mixed calculi with calcium oxalate dihydrate, calcium phosphate, and/or uric acid. Nine patients had calculi > 2 cm, 7 had calculi < 8 mm, and 23 had calculi between 8 mm and 2 cm. Seven of the 39 procedures were approached percutaneously. Follow-up consisted of an abdominal plain film after 2–4 weeks and a renal ultrasound after 3 months.

Instruments

Laser. The Ho:YAG laser (Coherent Medical Group, Palo Alto, CA) produces a pulsed energy light at 2,100 nm. On the device used, energy can be varied from 0.2 J to 2.8 J per pulse with a frequency range from 5 to 30 Hz. The light can be delivered through a low-water density fiber that is available in various sizes including 200, 365, 550, and 1,000 μm core diameter. The most commonly employed fiber is the 365 μm fiber, which requires a working channel of 2.2 Fr or greater. The depth of penetration from the Ho:YAG laser is < 0.5 mm. Unlike the Nd:YAG laser, the Ho:YAG does not cause forward scattering. Lateral firing fibers are also available. The specifications of the Ho:YAG laser are shown on Table 1.

TABLE 1. Ho:YAG Laser

Wavelength	2,100 nm
Energy/pulse	0.2–2.8 joule
Frequency	5–30 hertz
Fibers	200–1,000 μm (low water density)

Endoscopes. The endoscopes used for intrarenal treatment were either rigid or flexible instruments. Retrograde intrarenal treatment essentially required actively deflectable, flexible ureteroscopes (sizes from 7.5 Fr to 9.8 Fr). Antegrade intrarenal treatment was accomplished with either a rigid (22.5 Fr–24.5 Fr) or flexible nephroscope (16 Fr). All procedures were performed using the 365 μm fiber; thus the endoscope had to have a working channel 2.2 Fr or greater.

Endoscopic Ho:YAG laser technique. Once access is obtained, either antegrade or retrograde, the endoscope is placed in the intrarenal collecting system. The Ho:YAG laser fiber is then placed through the working channel of the endoscope. The methods to treat urinary calculi are different than the methods for intrarenal neoplasms.

To initiate stone fragmentation, laser frequency is usually set at 5 Hz and the energy/pulse is set at 0.6 J. The higher energy settings are used to treat harder calculi and higher frequencies may be used if the stone is not mobile.

Various techniques are employed to take advantage of the geometry of the stone to optimize fragmentation. In the *drill and core* method, the fiber is used to drill a hole in the center of the calculus. The center core is then removed by continuous activation of the laser fiber. Then, the outer layer is fragmented and removed. The *ablate and chip* method initially requires a hole to be created at the surface of the stone which is then enlarged by fragmenting from the edge of the cavity. A large central cavity is created and the peripheral stone is then removed. *Direct fragmentation* technique is reserved for smaller calculi or fragments of larger calculi. In this technique, the laser fiber is directly applied to the smaller calculi and activated, thus creating two or more fragments of calculi. The smaller fragments are usually able to pass through the ureter, whereas the larger ones may be removed with endoscopic graspers or baskets.

The Ho:YAG laser is also well suited for ablating and removing tissue. To use the Ho:YAG laser for tissue ablation, the fiber is initially set at a frequency of 8 Hz and the energy/pulse is set at 0.8 J. By increasing the frequency or energy/pulse, larger volumes of tumor can be treated. However, increasing the frequency will cause more tissue movement and increase the risk of injury to normal tissue. The laser fiber is placed near or in contact with the tissue that is being treated. The limited penetration (< 0.5 mm) offered by this laser gives precise control of the area for ablation and vaporization. The Ho:YAG laser energy is avidly absorbed by water; therefore, when the fiber is moved, a few millimeters away from the target the laser will lose its therapeutic effectiveness. The activation of the laser is used to remove tissue as well as to coagulate the tissue. The limited penetration and accurate control allow the urologist to treat neoplasms without injury to adjacent vessels or parenchyma.

These techniques can be used for calculi or neoplasms at any location in the urinary tract. Treating tumor or calculi within the intrarenal collecting system is different because the target moves with respiration and there may be difficulty in positioning the laser fiber. However, it can be used as an advantage by placing the activated laser fiber on the calculi or tumor and synchronized fragmentation or ablation can be performed with each respiration.

RESULTS

The Ho:YAG laser was effective in successfully fragmenting all types of calculi, including cystine and calcium oxalate monohydrate stones. The average total energy used to treat intrarenal calculi was 5.41 kJ, with a maximum of 37.77 kJ in one setting. The most common settings to treat urinary calculi were a frequency of 6 Hz and energy/pulse of 0.6 J. Among the 39 procedures for calculi, seven were successfully treated percutaneously. Antegrade use of the Ho:YAG laser was employed when calculi could not be fragmented by ultrasonic lithotripsy. After fragmentation by the Ho:YAG laser, the ultrasonic lithotripsy device was used to remove the fragments. The effectiveness of the Ho:YAG laser fiber did not change whether it was used in a retrograde or an antegrade fashion. There were no vascular or parenchymal injuries encountered in the treatment of intrarenal calculi. In the follow-up radiological assessment, there was no evidence of any renal loss or intrarenal strictures.

Thirteen patients underwent a total of 24 procedures for the treatment of intrarenal neoplasms. The average total energy used intrarenally was 2.61 kJ with a maximum of 15.28 kJ. The most common settings to treat intrarenal neoplasms were a frequency of 10 Hz and energy/pulse of 1.0 J. All patients were approached with retrograde flexible ureteroscopy. The primary neoplasm sites were distributed as follows: (1) 7/13, renal pelvis; (2) 4/13, upper pole calyx; (3) 1/13, middle and lower pole calyces; (4) 1/13, renal pelvis and upper pole calyx. Three of the 13 patients required multiple procedures to debulk their primary neoplasm. One patient required three procedures and the other two required two procedures for successful treatment. Five of the 13 patients had only one procedure for successful treatment of their intrarenal neoplasm. Five patients had recurrence of their tumor, and 4/5 of the recurrences were at a different location from primary site. Control of gross hematuria in the patient with high grade TCCa was obtained. Successful treatment of the primary neoplasms was accomplished in all patients with low grade TCCa. There were no vascular or renal injuries encountered. The follow-up intrarenal assessment of the collecting system did not reveal any strictures or renal loss. Tables 2 and 3 summarize our clinical data with Ho:YAG laser.

DISCUSSION

The endoscopic application of laser energy continues to expand. There are various lasers available for urologic use. The carbon dioxide laser, excellent for hemostatic ablation, is not compatible for use with fiberoptic endoscopes [6]. The pulsed-dye laser, the first approved laser for lithotripsy, can be used safely to fragment calculi. However, it is unable to fragment cystine stones and requires high energy to fragment calcium monohydrate stones [9,10,14]. Nd:YAG laser can be used to treat neoplasms. However, the Nd:YAG has forward scattering of laser energy; thus it can cause thermal injury to adjacent tissue. Also, when the Nd:YAG laser is used for treatment of neoplasms, it can coagulate tissue but does not remove it [8,9].

The Ho:YAG laser delivers pulsed energy at a wavelength of 2,100 nm through a small quartz fiber, which can insert easily through the working channel of most endoscopes. This wavelength

TABLE 2. Treatment of Neoplasms

Type of treatment	Number of patients	Number of procedures	Site of primary tumor
Single	5	5	4/5 renal pelvis 1/5 upper pole
Debulking	3	7	2/3 renal pelvis 1/3 upper pole
Recurrence	5	12	1/5 renal pelvis 2/5 upper pole 1/5 renal pelvis and upper pole 1/5 middle and lower pole
Totals	13	24	

TABLE 3. Experience with the Ho:YAG Laser

Intrarenal target	Energy (J)	Frequency (Hz)	Total energy (KJ) (mean)
Calculus	0.4–1.4 (0.5)	5–20 (5)	0.43–37.77 (5.41)
Neoplasm	0.6–1.2 (1.0) (select to start)	6–15 (10)	0.01–15.28 (2.61)

provides an ideal energy for tissue ablation, tissue removal, or stone fragmentation in a single device. The Ho:YAG laser can be used to ablate superficial low grade TCCa as well as to debulk large volumes of tumor. The Ho:YAG laser also can be used to control bleeding from neoplasms. The limited depth of penetration of this laser energy gives precise control when used for tissue ablation. It is effective in treating all types of calculi, including cystine and calcium monohydrate stones [8]. The stone is often broken into very small fragments and can be washed away with an irrigant. Another advantage of the Ho:YAG laser is the solid-state technology that requires minimal maintenance. In contrast, the pulsed dye laser uses a biodegradable dye that must be renewed as it degrades, usually monthly [5,8,11].

There are some drawbacks of the Ho:YAG laser. As with other lasers, the stiffness of the fiber may restrict the access and subsequent treatment of some intrarenal pathology. For example, the 365 μm fiber limits deflection of flexible ureteroscope to 90°. The Ho:YAG laser is capable of damaging normal tissue if the fiber tip is not positioned accurately while the laser is activated. This powerful laser is capable of cutting guidewires and if activated within the working channel can destroy the shaft of the endoscope. Also, during the treatment of urinary calculi or neoplasms, the scattering of debris or fragmented calculi can cause a "snowstorm" effect, which can be cleared by endoscopic irrigation. To avoid inadvertent injury to the urothelium, the fiber tip must be in direct vision when the laser is activated.

The intrarenal technique with the Ho:YAG laser differs from the ureteral technique. The intrarenal space is usually larger allowing for more deflection of the actively deflectable, flexible ureteroscope. This larger space allows for greater volumes of irrigant to be used especially when vision is not optimal. Access to the lower pole infundibulum is more difficult due to the stiffness of the laser fiber since the fiber limits deflection of the tip of the ureteroscope. In treating a lower pole calculus, irrigation and patient position can be used to dislodge the calculi into a better working area (upper pole or renal pelvis). A 200-μm fiber that does not restrict deflection of the ureteroscope has recently become available. However, neoplasms are not mobile. If access to a lower pole neoplasm cannot be obtained, other options such as electrocautery or percutaneous treatment may be employed [15].

As the use of endoscopy to treat intrarenal pathology continues to expand, it is essential to have smaller devices that can effectively and safely treat urinary calculi or neoplasms. Patients with symptomatic intrarenal calculi and who have failed shock wave lithotripsy are candidates for endoscopic Ho:YAG laser lithotripsy. Patients with low grade intrarenal TCCa and a solitary kidney, renal insufficiency, or bilateral disease are ideal candidates for endoscopic laser treatment for their neoplasms. Low grade TCCa of the bladder is routinely treated with endoscopic

resection and ablation. Endoscopic laser ablation of low grade upper tract TCCa may become an option for patients with unilateral disease and normally functioning contralateral kidney.

In our experience with 63 intrarenal procedures, the Ho:YAG laser was effective in fragmenting all types of calculi and effective in treating neoplasms. We did not encounter any vascular or renal injuries. There were no intrarenal strictures seen on follow-up radiologic assessment or endoscopy. We conclude that the Ho:YAG laser is effective and safe to use for intrarenal calculi or neoplasms. The Ho:YAG laser can be delivered through a small quartz fiber, which makes it ideal for endoscopic urologic applications.

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